

BY USING FAR-FIELD, NEAR-FIELD, AND COMMON-MODE TECHNIQUES, YOU CAN LOCATE EMI SOURCES AND THEN REDUCE THEM, SO YOU CAN MEET EMC GUIDELINES.

Three techniques guide radiated-emission sources

TODAY'S ELECTRONIC EQUIPMENT is usually very complex, and you probably have EMI issues to deal with. By identifying sources of radiated emissions, you can treat the offending sources and thus achieve the EMC you need.

Due to the proliferation of embedded electronic components, more commercial products now fall into classes of equipment that must meet strict environmental standards. Also, an increasing number of markets require that products adhere to EMC standards. Consequently, engineers find themselves with one foot in the time domain and one foot in the frequency domain.

In the design process, you have both design goals and design requirements. Although it is not good to miss a design goal, it's far worse to miss a design requirement. Falling short of a regulatory requirement, such as EMC, is not an option. However, EMC requirements are often at odds with other design requirements, so you must make some design trade-offs.

By using far-field, near-field, and common-mode troubleshooting techniques in the frequency domain, you can identify sources of radiated emissions. The far-field techniques closely resemble those techniques employed at large distances (meters) during formal EMC-qualification testing. The near-field and common-mode techniques are troubleshooting techniques that you perform at much closer proximity (centimeters). You could consider both of these last two techniques as near-field techniques. However, each technique has a distinct objective.

In antenna theory, the terms "near field" and "far field" have major implications with rather complex mathematical representations, but this article provides a simplified interpretation. As you gain EMC experience, you'll develop a personal troubleshooting style. However, the following approach has been

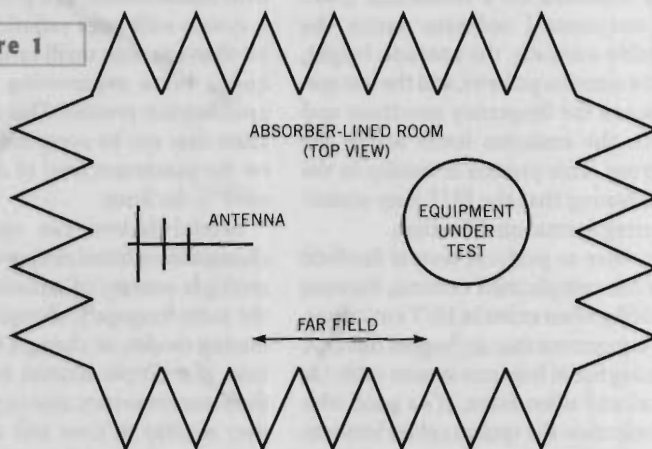
effective in reducing seemingly overwhelming EMI problems to a manageable set of issues.

BEGIN WITH FAR-FIELD ANALYSIS

Often, your first step in any troubleshooting process is to bound the problem to give you insight into both the severity and the nature of the problem. Because it is difficult to predict the far-field EMI behavior of your product by using near-field or common-mode measurement techniques, the most effective way to bound an EMI issue is to perform a far-field analysis.

Far-field analysis is a macroscopic look into the EMI behavior of the equipment under test (EUT) (Figure 1). You collect actual radiated-emission measurements over a range of frequencies and at a

Figure 1



In the far-field analysis, you measure the overall emissions at various orientations from your equipment under test, at a distance on the order of 10m, in an environment free of extraneous sources.

particular distance from the EUT and compare these measurements with predetermined limits.

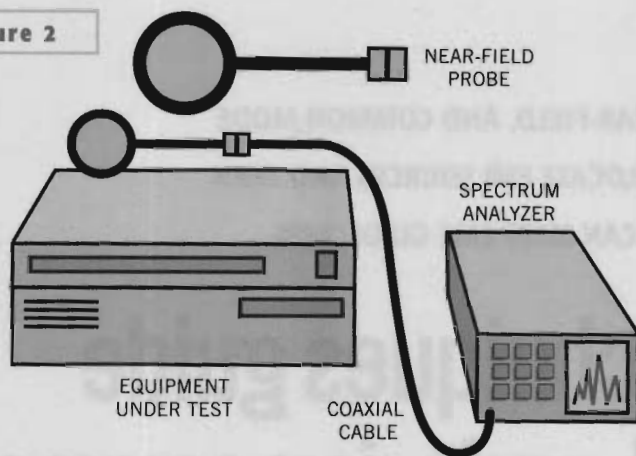
You gain maximum benefit if the measurement methods you use are the same as those methods that the applicable measurement standards define and if you do the measurements in an ambient-energy-free environment. Although the facilities and equipment you need to properly perform a far-field analysis can be costly, a sophisticated user can use these far-field techniques even with a crude facility.

In this discussion, "far field" refers to the distance between the receiving antenna and the EUT, as defined by the applicable measurement standards. For example, the European Standard EN55022:1995, Limits and Methods of Radio Disturbance Characteristics of Information Technology Equipment, states that the receiving antenna shall be 10m from the EUT when you take measurements. Special provisions allow for you to take measurements for Class B products at 3m. This standard is for the 30-MHz to 1-GHz frequency range; you can collect the data in an open-area test site or in an absorber-lined shielded room.

You can automate collection of far-field data by resting the EUT on a motorized turntable, with the receiving antenna mounted on a motorized mast. The test-control software varies the turntable azimuth, the antenna height, and the antenna polarity, and the test system scans the frequency spectrum and records the emission levels across the spectrum. This process is similar to the actual testing that the EUT may undergo during formal qualification.

You have to perform several far-field scans for complicated systems, because variability often exists in EUT emissions. Most equipment that undergoes this type of testing has at least one system cable (ac power) and often more. It's a good idea to manipulate the system cables between the far-field scan runs, because cable position can affect EUT emissions. Also, by viewing a select frequency or range of frequencies in real time while you are manipulating cables, you get instantaneous

Figure 2



For near-field analysis, you use a small magnetic loop antenna to pinpoint the source and frequencies of radiated emissions.

feedback, which leads to faster problem isolation.

A sign of a well-designed system is repeatable behavior, in which maximum radiated emissions vary by only about 2 to 3 dB at a given frequency in the far-field measurement. This result presumes that the radiated-emission levels are less than the required limits and that you have observed the EUT in all operating modes that could cause a significant change in the radiated emissions. It is sometimes difficult to determine whether this situation is the case.

A marginal design may produce extreme variations in radiated emissions—on the order of 10 to 20 dB—in the far-field measurement at a given frequency. A system with large variations is less stable than one with small variations and requires more engineering time in the qualification process. This extreme variation may not be acceptable, depending on the maximum level of emissions relative to the limit.

Several factors can cause extreme changes in radiated emissions, including multiple sources of emissions at nearly the same frequency, changes in EUT operating modes, or changes in cable position. If multiple sources exist at nearly the same frequency, one or more sources may overlap in time and thus produce emissions that add together. You may need to treat each source to reduce the emissions to the level you require.

Also, a change in a system operating mode can cause a significant change in

radiated emissions. For example, sudden bursts of disk activity or even microprocessor cache activity can cause corresponding sudden changes in emissions. To identify and treat these types of emissions, you may need detailed knowledge of the design. Finally, a large variation in radiated emissions due to cable position is a sign that there is something inherently wrong with the system. A properly designed system does not behave this way.

Causes for this large variation in radiated emissions resulting from changes in cable position are a poor grounding scheme, a poorly

filtered I/O port, a poorly shielded cable, or an aperture emission that couples onto an external cable. The steps you need to resolve these emissions can range from serious to simple and may require you to do a major redesign. This situation is not always the case, though, and sometimes simple steps solve the problem. For example, try replacing a poorly shielded cable with a well-shielded one or strategically placing an EMI gasket, which can virtually eliminate an emission by reducing the size of an aperture (an opening or slit in the enclosure). An emission from a small aperture can be particularly hard to find in the far-field test, because these emissions tend to be extremely directional. An aperture of just 5 cm may not provide your system with adequate attenuation at greater than approximately 900 MHz, so you need rigorous turntable and antenna positioning to locate this type of emission in the far field.

MOVE INTO NEAR-FIELD ANALYSIS

Near-field analysis simply requires you to have a spectrum analyzer and a near-field probe (a small magnetic loop antenna) (Figure 2). You pass the near-field probe close to the EUT (on the order of centimeters) while observing the spectrum analyzer. It's best to perform near-field analysis in conditions that are free of ambient RF energy. However, by using the knowledge you gain from a thorough far-field analysis, you can narrow the scope of the near-field analysis to the offending frequencies.

It is more practical to work in the presence of ambient frequencies when you have fewer frequencies to worry about, and this opportunity to simplify your testing can free up prime resources. Ideally, though, your far- and near-field techniques complement each other when you simultaneously apply them in an appropriate facility that is free of ambient energy.

A good starting point for your near-field analysis is to make a list of the precise frequencies that you measured during far-field analysis. However, other relevant information, such as the turntable azimuth, the antenna-mast height, and the antenna polarity where you measured the maximum emission, also provides you with valuable insight when you combine the information with a basic principle. This principle states that, in the far field, the polarization of the receiving antenna is orthogonal to the orientation plane of a radiating aperture.

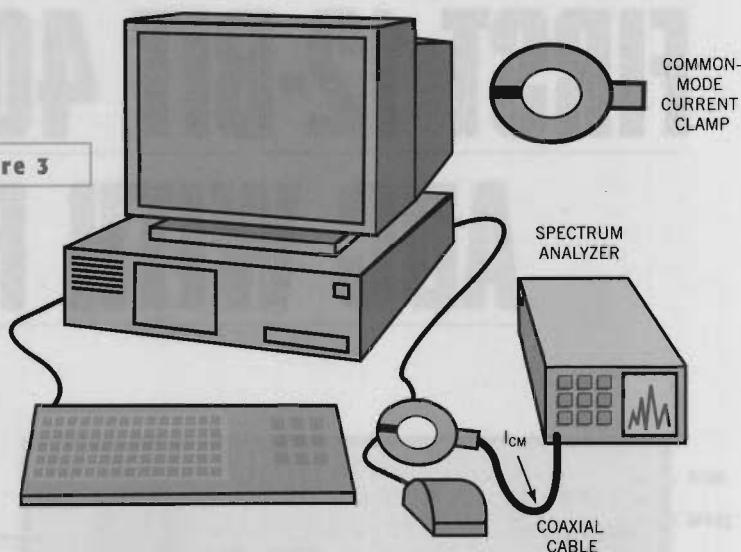
Thus, a vertical aperture in an enclosure produces a horizontally polarized emission, and a horizontal aperture in an enclosure produces a vertically polarized emission. By applying this knowledge while you are probing in the near field, locating and eliminating aperture radiation, which is your primary objective in this near-field analysis, becomes easier.

Slot emissions can be strong enough for you to observe them in the far field. But remember, you can observe even a weak slot emission in the far field if an external system cable passes close to an aperture. Also, routing of internal system cables can change the strength or even the frequency of an emission coming from an enclosure aperture.

You may want to perform near-field probing with the external system cables detached, because cables attached to the EUT can make it difficult to distinguish between cable emissions and slot emissions. Keep in mind, however, that there may be a trade-off in detaching system cables when you are doing near-field probing, because such detached system cables could preclude normal operation of the EUT. For example, if the operating system of the EUT resides on a hard drive that is external to the EUT, you need an external cable to run the operating system.

Enclosure apertures can occur as part

Figure 3



During common-mode analysis, you use a common-mode current clamp to locate cable-based emissions.

of your design, such as for airflow, or they can creep into the system by more subtle means, such as gasket fatigue, painted surfaces, or nonconductive metal coatings. In any case, you must eliminate apertures, even if only temporarily. To accomplish this task, you can use copper tape, aluminum foil, and an assortment of EMI gaskets, all of which are handy items to have in your arsenal of supplies.

At this stage of troubleshooting, you can use even crude methods of eliminating apertures. Generally, this stage is not the time to worry about whether you can implement a practical approach. It may turn out later, for example, that you don't need to eliminate the aperture, if you can treat the emission at the source instead.

Once you treat an offending aperture, your near-field probing near the treated area should verify that you have eliminated the aperture emission. You could also use the far-field spectrum to validate this fact. If the emission is still present in the far field, you may need to treat multiple emission paths (apertures or cables). When you believe that you have eliminated all offending apertures, you should do a far-field scan without cables attached to validate that you have eliminated the aperture emission. Although this type of far-field scan can give you insight, it is not representative of the actual operating mode. Nonetheless, the scan should indicate an improvement in the enclosure's overall integrity.

Next, restore the cables to the system and run another far-field scan under normal operating conditions. This step should indicate that you have made progress and have fewer or lower emissions. If emissions still exist, it's likely that they are cable emissions, and you need to do a common-mode analysis.

TRANSITION TO COMMON-MODE ANALYSIS

Common-mode analysis uses a test setup that is similar to the one you use for near-field probing. You simply replace the near-field probe with a common-mode current clamp to measure common-mode cable radiation (Figure 3).

Common-mode cable radiation is a direct result of stray currents traveling on a cable. These stray currents are due to an imbalance in signal current and return current somewhere in the system. Because current flows in only a closed circuit, return currents are just currents returning to their source.

Some currents on cables are intentional, and others are unintentional stray currents. You should always provide a low-impedance return path for the intentional signal currents.

If you properly balance signal and return currents, these currents are in equal and opposite directions, and the field that each current generates cancels the corresponding field. However, when a return path is inadequate somewhere within the system, the return currents follow an indirect, stray return path, and field can-

cellation cannot occur. The result is radiated emission.

Because cables make good antennas, it takes only a few microamperes of unbalanced, common-mode current to cause excessive radiated emissions. To measure these emissions, place the common-mode current clamp around the cable under test while you observe the display on the spectrum analyzer. As with near-field analysis, it is best to perform common-mode analysis in conditions free of ambient RF energy. However, by using the knowledge you gained from a thorough far-field analysis, you can narrow the scope of the common-mode analysis to just the offending frequencies, which makes working in the presence of ambient frequencies more practical. Ideally, though, far-field and common-mode techniques can complement each other when you apply them simultaneously in an appropriate, ambient-energy-free facility.

A good starting point for your common-mode analysis is to make a list of precise frequencies from your far-field analysis. Other relevant information, such as the turntable azimuth, the antenna-mast height, and the antenna polarity at which you measured the maximum emission, also provides valuable insight when you couple the information with a basic principle: In the far field, the polarization of the receiving antenna is in the same plane as the orientation plane of a radiating cable.

Therefore, a vertical cable produces a vertically polarized emission, and a horizontal cable produces a horizontally polarized emission. A cable having segments in both the vertical and the horizontal plane can have both vertically and horizontally polarized fields.

You should perform common-mode analysis on one cable at a time. If possible, detach any cables other than the cable under test from the system. Performing common-mode analysis with more than one cable attached to the system can cause interaction between the cable under test and remaining cables, which can invalidate the analysis. If other cables are present, you should route the remaining cables away from the cable under test so that there is minimal interaction with the cable under test. Finally, it is best if the enclosure is intact; if it is not, you may inadvertently invalidate the analysis if coupling occurs.

A GOOD STARTING POINT FOR YOUR COMMON-MODE ANALYSIS IS TO MAKE A LIST OF PRECISE FREQUENCIES FROM YOUR FAR-FIELD ANALYSIS.

Understanding cables can help you with troubleshooting. Coaxial cables are almost ideal, because their signal currents and return currents (and, therefore, the generated fields) are contained within the shield of the cable. However, because it is often infeasible to use coaxial cables throughout the system, you must make accommodations for more practical cabling options. With this cable trade-off, you get higher radiated emissions.

If a break exists in a cable's return path, such as from a broken shield or a broken drain wire, the cable radiates. It is best to work with trusted cables that have a history of passing emission tests. But even these trusted cables eventually fatigue and begin to radiate. The best way to perform a cable check is to place the common-mode current clamp around the suspect cable and then observe the cable's emissions on the analyzer. Flex the cable at the terminations, which are its weakest points. If an intermittent connection exists, the field that the common-mode current clamp measures jumps at least 5 to 10 dB.

You can also perform a cable check using a milliohm-range meter to measure the resistance of the cable shield between each connector back shell. Again, flex the cable at the terminations while watching for radical changes in resistance. This technique can be less reliable because it employs a dc rather than an RF measurement technique, but it is easier to use in some cases.

CLOSE WITH THE ROOT CAUSES

When you have eliminated all of the enclosure apertures and have put trusted cables in place, you should have only a handful of offending emissions to troubleshoot, because you designed the system for EMC. Your next step is to identify and treat the causes of these offending emissions.

At any given frequency, the emissions can have harmonic content from numerous sources. For example, a 200-MHz emission can have harmonic content associated with fundamental frequencies of 25.00, 33.33, 40.00, 66.66, and 100 MHz, and the core frequency of a microprocessor can also be at 200 MHz. Only one of these many sources may be your main offender; the others may be much smaller causes.

Fortunately, at the offending frequency, the harmonics associated with each of these sources are rarely at precisely the same frequency. A few tens of kilohertz perhaps separate the harmonics. You can use this precise information to get to the root of the problem, but creative use of the spectrum analyzer is crucial here. The analyzer allows you to carefully differentiate between the individual contributing sources at the offending frequency. You can apply a combination of far-field, near-field, and common-mode troubleshooting techniques to properly perform this analysis.

Starting with the far-field test setup, set the spectrum analyzer to a span of about 1 MHz at the offending frequency and place it in autocoupled mode. At this span, you can't distinguish the individual signal contributors from one another. Begin stepping down the span until the individual contributing frequencies become apparent. While stepping down in span, continue to keep the highest contributor or contributors centered on the spectrum-analyzer display. Note that, in an autocoupled mode, the sweep time, the resolution bandwidth, and the video bandwidth of the spectrum analyzer automatically change to a setting appropriate for the selected span.

Once the spectrum analyzer's span is sufficiently narrow, the individual contributing frequencies become distinct. You can now determine with great precision the frequency of the main offending contributor or contributors. Record this frequency and turn to the common-mode test setup for correlation. Use the same analyzer technique with the common-mode test setup to identify which cable (or cables) is the path of the emission at the exact frequency in question. Here, you are looking at relative levels of emissions at the precise offending frequency. This approach can steer you to the offending port or ports.

After you gain access to the enclosure,

use the same analyzer technique at the circuit level, but with the near-field probe. Again, look at relative levels of emissions at the precise offending frequency. Pass the near-field probe close to the circuit components of the EUT.

Near-field probing at the circuit level can point you to pc-board-layout problems, such as faults in a ground plane or noisy traces due to crosstalk. This probing can also highlight components with inadequate decoupling or excessive package radiation, or component placement problems causing coupling between subsystems. You can then use careful cause-and-effect troubleshooting techniques to deterministically get to the root of the problem. For example, by removing a filter component on an I/O port, you might see a reduction in emissions at the precise frequency in question in the far field, in the near field, and with the common-mode setup.

Once you identify an offending source, you can determine which of the design rules you violated in the design process and correct the design, thus treating the

NEAR-FIELD PROBING AT THE CIRCUIT LEVEL CAN POINT YOU TO PC-BOARD-LAYOUT PROBLEMS, SUCH AS FAULTS IN A GROUND PLANE OR NOISY TRACES DUE TO CROSSTALK.

source. A design that is well-thought-out includes some level of flexibility so that you can make such corrections. For example, you can tune clock terminations or I/O-port filters if the circuit topology is already in place.

REPEAT UNTIL DONE

Solving the emissions problem is not a straight-line process, and you may have to repeat the process—or portions of it—until you treat all offending sources. An-

other far-field test and analysis will ultimately validate your results. If the far-field analysis produces a favorable result, you can systematically start deleting any temporary fixes that you may have implemented during troubleshooting. Some or all of these changes may be unnecessary once you have the source of the emission under control. If you implemented a temporary fix earlier in the troubleshooting process that you now see is necessary, you have to devise a reasonable, repeatable approach. □

AUTHOR BIOGRAPHY

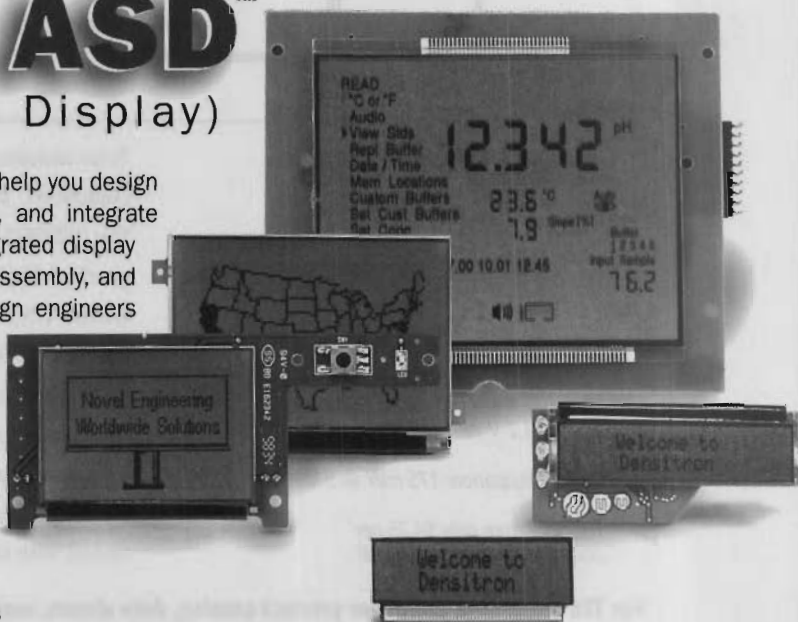
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